

fast enough to resolve the signals present in DNA sequencing. To overcome this problem, researchers have developed a custom amplifier that has reached a bandwidth of approximately 1MHz, being able to reveal additional information during the DNA translocation events through a nanopore.

We will demonstrate a design of a custom amplifier that offers a wider bandwidth than the current designs, enabling the study of DNA translocation without the need to limit the speed of translocation. In addition, an amplifier with a bandwidth larger than 1MHz allows discoveries to be made about information that might be present in a higher range of frequencies, enabling measurements at a higher time resolution than what was previously possible. The amplifier will be designed to allow direct integration of a micro- or nanopore sensing area on the same physical substrate, eliminating the need for external electrode wiring. The outcomes from this research open up the possibility of an integrated high-speed DNA sequencer chip enabling rapid disease diagnostics.

#### 1069-Pos Board B824

##### Diffusion and Trapping of Single Particles in Pores

Matthew Schiel, Zuzanna S. Siwy.

University of California, Irvine, Irvine, CA, USA.

Passage of single molecules and particles through pores is the basis of resistive-pulse sensing. We introduced an additional control of the particle transport by modulation of the driving voltage during the translocation process. Balancing all forces acting on the particles allowed us to observe diffusion of single particles in the pore, and quantifying their diffusive coefficient. The developed method for measuring diffusion coefficient in pores is applicable to particles of different sizes, does not require fluorescence labeling, and is entirely based on ion current recordings. Application of a modulating voltage signal together with rising edge triggers enabled transporting the same particle back and forth within the pore without letting the particle leave the pore. This method is especially useful for the analysis of species present in a solution in low concentrations where statistics on an ensemble of particles/molecules has to be replaced by the statistics based on one particle studied many times. The experiments were performed with negatively charged polystyrene particles passing through single 11  $\mu\text{m}$  long pores in a polyethylene terephthalate (PET) film. The pores were prepared by the track-etching technique, which when applied to PET films leads to pores with undulating diameter along the pore axis. The pore topography is reflected in the pulse shape. Passage of particles through narrower parts of a pore causes a larger change of the transmembrane current compared to the case when the particles pass through wider pore segments. Each particle 'follows' the same pore topography thus all current pulses for a given pore look alike. We used the ion current pulse substructure as reference points for particle position along the pore axis, which facilitated the determination of diffusion coefficient of translocating particles.

#### 1070-Pos Board B825

##### Controlling Motion of DNA in a Nanochannel with Transverse Alternating-Electric-Voltages

Binqian Luan, Chao Wang, Ajay Royyuru, Gustavo Stolovitzky.

IBM Research, Yorktown Heights, NY, USA.

One key requirement for fast and accurate DNA sequencing in nanopores or nanochannels is to control the DNA position and modulate the speed, which, however, still remains a big challenge. Because of drastically changed electric potentials across a nanochannel, the DNA motion is too rapid for a sensor to detect each DNA nucleotide. A nanofluidic channel, with a pair of perpendicularly aligned nanoelectrodes, is proposed to electrostatically control the motion of DNA molecules. Using all-atom molecular dynamics simulations, we studied electrostatic responses of a charged DNA molecule in the nanochannel and investigated optimized operating conditions for controlling the motion of the DNA. When the transverse electric field was periodically turned on and off, the DNA molecule was correspondingly immobilized on and released from the channel surface. Under simultaneously applied longitudinal biasing and transverse trapping electric fields, the DNA molecule moved forward in a "ratchet"-like fashion. It is expected that achieving the controlled motion of DNA in the channel can advance studies and applications of a nanochannel-based sensor for analyzing DNA (e.g., DNA sequencing).

#### 1071-Pos Board B826

##### Disentangling Steric and Electrostatic Factors in Nanoscale Transport through Confined Space

Steven F. Buchsbaum<sup>1</sup>, Nick Mitchell<sup>2</sup>, Hugh Martin<sup>3</sup>, Matt Wiggin<sup>4</sup>, Andre Marziani<sup>4</sup>, Peter V. Coveney<sup>3</sup>, Zuzanna Siwy<sup>1</sup>, Stefan Howorka<sup>2</sup>.

<sup>1</sup>Physics, University of California, Irvine, Irvine, CA, USA, <sup>2</sup>Chemistry, Institute of Structural Molecular Biology, University College London, London, United Kingdom, <sup>3</sup>Chemistry, Centre for Computational Science, University College London, London, United Kingdom, <sup>4</sup>Physics and Astronomy, University of British Columbia, Vancouver, BC, Canada.

The voltage-driven passage of biological polymers through nanoscale pores is an analytically, technologically, and biologically relevant process. Here we exploit an experimentally tunable system to understand and quantify the relative importance of electrostatic and steric interactions in nanopore analytics. The approach provides understanding of previously unresolved fundamental aspects of pore transport particularly of biopolymers which vary in charge and volume along their sequence. Our tunable experimental system is based on a common DNA oligonucleotide of 27 nucleotides which carries at an internal base position a positively charged oligoarginine tag of three, five, or seven residues or a negatively charged hexa-aspartate tag. An applied voltage was used to drive these modified oligonucleotides through the inner constriction of an alpha hemolysin pore embedded in a lipid bilayer causing a measurable drop in ionic current. Statistical analysis of large numbers of event durations provided the characteristic translocation time ( $t^*$ ) in each case. A biophysical model was then developed to describe  $t^*$  as a function of voltage and arginine/aspartate tag lengths. Through best fit analysis this model generated reasonable oligonucleotide charge and basal hopping rate values. Further, this model allowed us to predict the impact of only steric or electrostatic effects providing insight on the relative importance of each. This new, fundamental framework facilitates the understanding of how complex biopolymers are transported through confined space and indicates how their translocation can be slowed down to enable future sensing methods.

#### 1072-Pos Board B827

##### A Simple, Single-Carbon-Nanotube Nanofluidic Platform for Fundamental Transport Studies

Shirui Guo<sup>1</sup>, Matthew Davenport<sup>1</sup>, Eric Meshot<sup>1</sup>, Steven Buchsbaum<sup>2</sup>, Zuzanna Siwy<sup>2</sup>, Francesco Fornasiero<sup>1</sup>.

<sup>1</sup>Physical and Life Sciences, Lawrence Livermore National Lab, Livermore, CA, USA, <sup>2</sup>Department of Physics and Astronomy, University of California, Irvine, Irvine, CA, USA.

Fundamental understanding of ionic and molecular transport phenomena in a simple model nanopore is critical for elucidating function mechanisms of much more complex biological systems, and for advancing technological areas such as membrane separation, energy harvesting/storage, and single molecule detection. For this goal, carbon nanotubes (CNTs) offer key advantages as model nanofluidic channels due to their simple chemical composition and structure (known with atomic precision), robustness, facile length and diameter control, and straightforward local functionalization at their open rim. CNTs have also very interesting fluidic properties such as enhanced pressure-driven fluid transport rates, unusually high electroosmotic flow, and ionic selectivity. Here, we present our work toward developing and validating a novel nanofluidic platform featuring an individual carbon nanotube (CNT) as the flow channel in an advanced Coulter Counter. To fabricate the CNT nanofluidic device, vertically aligned single-walled CNTs are synthesized directly on a suspended silicon nitride membrane and then bound in a solid matrix before an individual CNT is opened by focused ion beam milling. Single-molecule translocation studies with small molecular size analytes suggest the successful fabrication of a Coulter Counter with a few-nm wide CNT nanochannel. Our initial ionic conductivity studies indicate a power-law increase of conductance with KCl concentration in CNT channels, a dependence that seems to be unique of CNT pores.

#### 1073-Pos Board B828

##### Double Occupancy of a Protein Pore as an Intermediate State of Competition at the Single Molecule Level

Gerhard Baaken, Anne-Katrin Schuler, Marcel Hoffmann, Jan C. Behrends.

Physiology, University of Freiburg, Freiburg, Germany.

Alpha-hemolysin nanopores are used to detect single oligomers of poly(ethylene-glycol) (PEG) which under high salt conditions reside in the pore for extended periods of time (up to several ms) suggesting binding to the pore's inner wall. We study the interaction of two species of PEG of degree of polymerization 28 and 32 which, following sequential entry, simultaneously reside in the pore. This doubly occupied (DO) state can result in direct replacement of the first occupant by the second. Analyzing the dwell times of the DO states, we ask whether binding as a first or second pore occupant is equivalent in terms of stability. We find that the DO state lifetimes are shorter than would be predicted by simple superposition (see Figure). We conclude that binding in the pore as the second occupant is highly unstable, suggesting that the more stable primary binding state cannot be attained by more than one PEG molecule. The doubly occupied state thus represents an intermediate state with possible general relevance for competitive interactions at binding sites to which access is gained through long channels, such as in some enzymes.

